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AUTOKINETIC SENSATIONS

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H. F. A.

THE AUTOKINETIC SENSATIONS[1]

Introduction

The visual illusion of motion known as the Autokinetic Sensations has had a curious and interesting history. First discovered by Humboldt in 1799, while he was observing the stars, it continued in astronomical literature for over half a century.[2] It was thought to be an actual movement of the heavenly bodies, which, like an eclipse, could be best seen in certain places and under certain conditions, and could be foretold with mathematical accuracy.

It was not until after the middle of the nineteenth century that the *Sternschwanken* was found to be an illusion.[3] Since that time, the illusion has appeared as a by-product of other experiments, principally those performed in the dark room, and has sometimes been reported by the investigators as a new phenomenon. Little thoroughgoing experimental work has been done on the illusion.

It is possible to experience the illusion either by fixating for a few seconds a star, or a faint light in the dark room, or a black spot on a white surface. Under these three conditions, the illusion shows certain similarities, movements being present, but

[1] The illusion, which refers to the apparent movement of a faint, stationary light in the dark, owes its name to Aubert (6).

[2] Humboldt (1) first observed the phenomenon from a mountain peak in Teneriffe very early in the morning of June 22, 1799. The movement of the stars, often of considerable magnitude, was visible either with the naked eye or with a telescope. It lasted for seven or eight minutes, but stopped long before the rising of the sun. Thinking that the stars actually were moving, Humboldt gave the name *Sternschwanken* to his discovery.

[3] Schweizer (2) proved the movement to be illusory by having the same star watched simultaneously by different persons. Each saw it moving in a different direction. The author was unable to procure a copy of Schweizer's work, but found an abstract of it in an article by Exner (8).

there are differences in rate, amplitude and character of the movements.[1]

In the experiments set forth in this paper, a faint light in the dark room was used throughout, for it made possible greater flexibility in controlling conditions. The subject was suggested by Dr. Harvey A. Carr of the University of Chicago, who had already done some preliminary work in studying the illusion. The following experiments are a continuation of his. Where his experiments were qualitative, these, as far as possible, have been made quantitative, and several points left untouched by him have been investigated.

[1] The movements of the black speck on the white surface are all of small extent and there is a well defined tendency for the speck to return to the starting point. Schweizer (2), Hoppe (3), Aubert (6), Bourdon (9).

The *Sternschwanken,* according to Charpentier (4), is quite different from the illusion produced by fixating the faint light in the dark room. He alleges that in the former, the movement is small, changes direction rapidly, and slight concomitant eye movements can be noticed. In the latter, these conditions are reversed.

According to Aubert (6), distant objects, the contours of which are not sharply marked, may also appear to move.

APPARATUS AND METHOD.

The light which was used as a fixation object was a two candle-power incandescent electric light enclosed in a light-tight box. The box had a changeable cover, in which was pierced a hole of desired size and shape. This hole was covered with one or more thicknesses of white paper to reduce the brightness of the light and to prevent direct fixation of the filament. The brightness was regulated by the number of pieces of paper pasted over the opening.

The light was hung in the center of the wall which constituted the field of vision, at a distance of 200 cm. from the eye of the observer. The visual field was divided as follows:—the immediate point of reference was the zero point, or point of no illusory movement as determined by Carr (15) in his experiments on visual illusions due to eye closure. This point or area was found in his investigations to be with most persons slightly below the primary fixation position. Horizontally, vertically and on the two diagonals, points 10, 20, 30 and 40 degrees from the zero point were measured off, and nails driven above them so that when the box was hung from the nail, the spot of light would be directly on the appropriate degree mark. In this way, 33 positions in the visual field were marked off for examination, i.e., the central point and 32 peripheral positions.

The head of the subject was held firmly in a mouth-bit head-rest. This was done for two reasons:—first, to keep the head relatively stationary during any one fixation; and, secondly, to enable the subject to get back to the same position with reference to the field of vision time after time. The head-rest was so adjusted that the right eye of the subject, for which the zero point had been obtained, was 200 cm. from the light. Because the visual field was a flat surface, the points towards the periphery were increasingly distant from the eye of the observer.

A telegraph key, time marker, and kymograph drum were also used for registration purposes after the experiment had progressed slightly.

The method used was in many respects similar to that of all of those who have worked upon the illusion. The subject was seated comfortably in a chair, and, at a signal, took position in the mouth-bit head-rest. The illumination in the room was turned out and, after a sufficient interval had elapsed for him to get rid of the bright after-glow and after-images, the subject fixated the spot of light on the wall. Immediately upon fixation, the observer pressed the signal key. When the illusion started, the key was again pressed, thus giving the rate of start of the illusion. From the beginning of the illusion, the fixation lasted for 60 seconds. During the observation, the subject pressed the telegraph key once for each noteworthy thing which happened, such as turns in the direction of the apparent pathway of the light, stopping, starting again, etc. This time record was traced on the kymograph drum which was in a near-by room. At the end of the minute, the fixation was discontinued, the illumination in the room turned on, and the subject traced on paper from memory the approximate pathway of the illusion, putting a cross on the paper to correspond with each of the signals given by the telegraph key. In this way, it was possible to measure the duration of the illusion in any particular direction, the length of time it took it to start, the duration of any pause, etc.

Two of the subjects found it impossible to give an estimation of the linear or angular length of the illusory movement. It was necessary, therefore, in order to secure uniformity in treating the results, to substitute duration of movement for length of pathway in a given direction. This was often unfair, for the light might make a short, slow movement which would take a longer time than a long, fast one. But it seemed to be the only possible way of getting any quantitative results, so it was adopted.

The fixation light was hung first at the zero point, where it was fixated four times in succession, with a regular two minute interval between fixations. The ten degree points were then explored in the same manner and so on through the 30 and 40 degree positions. The next series was begun at the periphery and worked in towards the center.

This method was used for several reasons. In the first place,

it was desired to make the work as definitely quantitative as possible. For this purpose, accurate measurements of some kind were necessary. In the second place, all of the previous work upon the illusion had been of a very general and incidental nature. According to the reports of the various previous experimenters, the instructions given to the subjects were rather vague. If the subject had any preconceived notion of what should happen, that very thing was likely to occur during the course of the illusion, if he observed it long enough, thus making it more or less possible for the subject to control the results. For that reason, a regular time interval was used throughout. In the third place, the duration of one minute was used because it was found empirically that that duration gave the best results with the least possible fatigue.

The greater part of the work fell upon four subjects, M. R. F., J. W. H., H. A. C., and H. F. A., although about 50 more were used incidentally. No conclusions are based upon the results of fewer than two subjects, and in most of the tests from three to six were used. Of the subjects indicated by initials above, all but M. R. F. wore glasses.

Each of the subjects but one, J. W. H., was found to have a zero point. With him, a point ten degrees below the primary position was used as the point of reference.

METHODS OF SCORING RESULTS.

When the results were looked over, it was found that the ordinary pathway of the illusion was very far from being a straight line. It was often extremely crooked, having turned in as many as eight or nine different directions. The question then arose: What is the fairest and most accurate way of recording these results? It is quite obvious that the directional factors may be of some importance, but these factors often do not act regularly and continuously. For certain positions in the visual field it seemed to be entirely accidental when the light went in exactly the same direction twice in succession even with the same subject. In order not to make the results too unwieldy, the 360 degrees of a circle were divided into eight equal segments, each covering 45 degrees of arc. If the apparent pathway of the light fell twice in the same segment, it was said to be in the same direction. This arrangement allowed movements with a maximum variation of 22½ degrees to be recorded as in the same direction. By this means, each successive direction of the pathway was noted and averaged for each series of four tests, so that it was possible to find out in what directions the light tended most strongly to go. Not only was the frequency of movement in any direction recorded, but also the time that the light spent in going in that direction. These two results were reduced to percentages and averaged in obtaining the final results which are given in this paper.

EXPERIMENTAL RESULTS.

The first thing done was to determine the norm of behavior of the square light for the 33 positions on the visual field. Lights of different shapes were used to determine the effect of the shape of the fixated object on the direction of the illusion. A series of tests was then run through with lights of the same shape, but of different sizes. The illusion was then tested under conditions of monocular and binocular vision. Tests were also made to find out how great a part suggestion of a direction played in making the light go in that direction. The possibility of voluntary control of the direction and of the amount of the illusory movement were taken up and incidental tests made concerning the effect of the brightness of the light upon the characteristics of the illusion; the latter topic being one which others have investigated with some completeness.

I. EXPERIMENTS WITH WHITE LIGHT 1 CM. SQUARE.

A. Universality of the illusion.—Of over fifty subjects experimented upon to test this point, not one was found who did not experience the illusion under some conditions. Sometimes several trials were necessary before the illusion took place. In the case of subject F., reported by Carr (14) as being unable to experience the illusion, it was found that when she was prevented from knowing whether the light was really stationary or moving, the illusion took place, although the light was of course actually motionless.[1]

B. Rate of start of the illusion.—On account of defects of

[1] Exner (8) reported that two of his observers could not get the illusion in a single trial. Charpentier (4) says that nearly all of his subjects experienced the illusion, but does not mention the percentage of those unable to do so, nor does he say anything about the conditions under which they were tested.

the apparatus and even more on account of difficulties of judgment, the results obtained in getting the rate of start have a constant error of about one second.

The average rate of start of this light for a total of 1960 trials with six subjects was 6.1 seconds. There is, however, a considerable variation in the rate of start of the illusion with the same subject, not only for different parts of the visual field, but also for the same part at different times. This variation seems to depend upon numerous factors. After-images often cause considerable delay in the starting of the illusion. Practice has the effect of making the light start its apparent movement more quickly. At the beginning of the series, the average rate of start for M. R. F. was 10.62 seconds. After having served as subject in the experiment for a year and a half, the time was reduced almost two-thirds. Certain other factors, such as the size of the light, will be taken up below.[1]

The variation for the different parts of the visual field for the same subject showed that the quickest rate of start occurred at that part of the field showing the greatest regularity in the direction of movements for successive trials. This ordinarily occurred towards the extreme periphery. The apparent exception to this rule was found in the case of H. F. A. With him, the fastest rate of start was at the center of the visual field. But even at that position, the illusion was quite regular in type,

[1]In the literature, the rate of start of the illusion has been almost entirely neglected. Aubert (6), the only one who committed himself, places the time at 30 to 40 seconds. Fatigue has been mentioned as a factor which makes for the quick production of the illusion. Charpentier (4) says that the illusion takes place most easily after prolonged mental labor, such as a lecture, a long conversation, etc. Bourdon (9) maintains that retinal fatigue was found to be a favorable condition for the production of the illusion, as were also fatigue of the eye muscles, general fatigue and mental fatigue. Stimulation by alcohol and tobacco makes the illusion take place more readily. Carr (14) found that with marked fatigue of the eye muscles, the illusion started before the light could be directly fixated.

It is almost impossible from the literature to determine whether the investigators were referring to the rate of start of the illusion, or the rate of the apparent movement after it had started, or the ease with which it was produced. However, none of the previous investigators kept any exact time record of the rate of start of the illusion, their conclusions being based entirely upon impressions received in the course of their experiments.

generally describing a clock-wise curve, the irregularity occurring at the points at which the illusion started and stopped.

There is also a well defined tendency for the rate of start to be quickest for those subjects who experience the illusion most markedly, as regards both rate and extent of movement. With the new subjects, the illusion was always slow in starting, while with H. A. C. who had observed the illusion more than any other subject, it took place immediately upon fixation in the great majority of the cases.

C. Direction of movement.—At the center of the field of vision, the pathway of the light for any one subject was very erratic. Nor did the light describe the same pathway for any two individuals in this portion of the field. The further towards the periphery the light was placed, that is, the more eye strain that was necessary to keep the light foveally fixated, the more likely was the direction of the apparent movement to be regular both for the same subject in different tests and for different subjects. The direction of this apparent movement tended to be in the direction in which the eye was turned. If the eye was turned to the right while fixating the light directly, the light showed a tendency to move to the right; and the more the eye was turned in that direction, the more likely was the light to move in that direction without variation. In the following table is given the peripheralwards tendency of the light. In the one case is given any peripheral tendency whatever, and in the other is given the tendency of the light to go in the exact direction of the eye strain. The results are given in percentages, averaged for six subjects and all positions on the visual field, a total of 1960 tests.

	10°	20°	30°	40°
Peripheral tendency	70	77	87	94
In direction of strain	26	34	56	91

This table brings out very strikingly the effects of eye strain on the direction of the illusion. The light seldom goes over the same pathway twice except at the extreme periphery, but merely shows an increasing tendency to go in a given direction time after time the farther from the center of the field the light is placed.

With each observer, there are one or more directions in which the light seems to "prefer" to move when at the more central portions of the visual field. With M. R. F. the tendency for the

light to go in the right-left direction was much greater than for it to go either up or down. With J. W. H. and H. F. A. the light had a decided upward tendency. It is interesting to compare the upward tendency of the illusion with these two subjects and the similar tendency of a fading negative after-image.

There is a fairly large average variation between two series with the same subject and the same light. The average variation for the whole field, found by taking the difference in percentage of appearance in each segment for any two series, and getting the average of that, was found to be as follows for the two subjects whose results represent the maximum and minimum.

H.A.C.	Whole field	5.00
	Highest	6.39
	Lowest	1.96
M.R.F.	Whole field	8.89
	Highest	18.75
	Lowest	0.00

In this connection, it may be interesting to ask whether the direction of the apparent movement of the light remains constant through long periods of time. Two persons who had served as subjects in Carr's experiments were also subjects in these. A comparison of the results of the two investigations showed a very great uniformity of the pathway in the peripheral portions of the field of vision. The same general tendencies and peculiarities held quite constantly for each subject even after the lapse of almost two years.[1]

[1] Since, in most of the experiments reported, the light was approximately in the center of the field of vision, the direction of movement was not constant. With Humboldt (1), the movement of the start was either up or down or circling, with an invariable return to the original position. Schweizer (2), in referring to the movements of the stars, says that the movement is either circling or straight. In speaking of the apparent movement of a faint light in the dark room, Charpentier (4) states that while this movement is large and continuous in one direction, the direction may change after a time. He denies that the position of the eyes in the head has any effect upon the direction of the illusory movement. Exner (8) maintains that the direction of the movement depends upon the direction of the line of regard, but does not state in what way. Hillebrandt as quoted by Aubert (6), Bourdon (9) and Carr (14), say that if the light is in the periphery of the field of vision, the movement is in the direction of the eye strain. Exner (8), Gould (11) and Carr (14) call attention to the fact that there are individual peculiarities in the behavior of the light.

D. Rate of movement. The rate of movement is very irregular. The light seldom, if ever, starts out at full speed, nor does it stop suddenly, but accelerates and retards. Under the conditions of this experiment, the rate, as estimated by subjects H. A. C. and H. F. A., was seldom more than 10 degrees per second, and this speed was attained only at the extreme periphery. The light may move smoothly and continuously, or it may move in jerks.

Any disturbing factors, such as after-images, a second light in the field of vision, etc., made the movement much slower, if they did not check it entirely. When a screen was hung between the subject and the fixated light so that crossed strings appeared on the surface of the light, the illusion was very much slowed up. It gave the impression of a very small object trying to pull a heavy load along with it.[1]

E. Extent of movement. The extent of the illusory movement varied quite markedly for different subjects. For some it was very slight and so slow as to be hardly noticeable, especially at the central portions of the field of vision. In all cases, the angular displacement was greater towards the periphery. In this position, it often amounted to 40 or 50 degrees for some of the subjects. Ordinarily the light kept moving as long as it was fixated; in the central part of the field, however, the pathway was coiled up, while at the periphery it was straightened out, thus making the movement seem much more extended.

Two of the subjects were unable to tell with any accuracy the angular or linear extent of the illusion. Probably this lack of ability arose from three conditions: first, lack of knowledge on the part of the subject as to what a certain number of degrees represented; secondly, the lack of any fixed points of reference in the visual field; and third, because after the light had gone for some distance, it sometimes appeared, without any adequate movement, suddenly to be back very close to the starting point.

[1] Charpentier (4) found the movement to be like that of a shooting star, but less rapid, having an apparent angular velocity of 2 or 3 degrees per second. Carr (14) found that under conditions of extreme ocular fatigue due to constrained eye position, the light often appeared to move 15 or 20 degrees per second, while under more normal conditions it was much slower.

This was due to some sort of revaluation of the ideational space construction of the subject.[1]

When, in the estimation of the subject, the light, in its wanderings, had approached one of the boundary walls of the room or the floor or ceiling, it often seemed to turn the right-angled corner and move either towards or away from the subject, though at other times it seemed to go straight through the walls. With J. W. H. the light, on one occasion, went straight down until it seemed to rest upon the floor. It "tried" to go down still farther and in its "efforts" apparently tipped the room, furniture and subject through an angle of almost 20 degrees. What actually happened was that the subject, in his endeavors to keep the light fixated, had tilted the table on to two legs and was holding it in that position solely with the mouth-bit head-rest while trying to keep his own balance.

This fact brings out in a striking way the illusion of eye movement which accompanies the apparent movement of the light. The subject is often vividly conscious of pursuit movements which he thinks he is making in following the light. This is more strikingly true for the more peripheral portions of the visual field. But when the illumination in the room is turned on, the subject finds that the eye has not wandered from the light which is in its original position. At times, even, there is a simultaneous illusion that the table or mouth-bit head-rest is going in the direction opposite to that of the light, though this is not always the case. One of the subjects actually twisted the head-rest loose from its support in his endeavor to follow the movement of the light.[2]

[1] Charpentier (4) holds that the extent of the movement may be large, amounting even to 30 degrees in extent. Bourdon (9) agrees with Charpentier as to the extent of the movement, and states in addition that the light sometimes reaches a fixed limit, undergoing slight abrupt displacements from time to time about this final position. Carr (14) holds that under conditions of ocular fatigue, the extent of the illusory movement may be as much as 65 degrees, though this takes place only on the outlying portions of the visual field and with certain subjects only.

[2] Exner (8) calls attention to the fact that the fixation of the light is evidently much more constant than under ordinary conditions. Bourdon (9) found that there is a false consciousness of the direction of the line of regard. If the point had seemed to go up 20 degrees, the observer was

Even when the light was apparently nowhere near the boundary walls, illusory movements in the third dimension were not uncommon. These were often accompanied by a blurring of the outlines of the light.[1]

F: Suggestions due to the form of the light.—The shape of the light had some effect upon the qualities of the apparent movement. A round light, 1 cm. in diameter, often gave the impression of a balloon, floating freely through the air. Its turns were seldom angular, seldom abrupt, but generally through an arc of a circle. Often when turning in a curve, the light seemed to spin like a billiard ball in a masse shot. It was possible for this light to go as fast in one direction as in any other, there being nothing in the shape of the light which would tend to check movement in any direction.

The square light, 1 cm. square, often suggested a boat going through the water, especially if its course were such that it seemed to be going diagonally. This light, unlike the round one, seldom, if ever, turned through an arc, but usually through a sharp angle. Like the round light, it could go in all directions with equal facility.

The long, narrow light, 5.6 cm. by 0.18 cm., often reminded the subject of a board being raised or lowered or falling through the air. The movement was always fastest when the light was going in the direction of the long axis, and very slow when in the direction of its short axis. When this light appeared to go in any diagonal direction, it sometimes went like a sail boat with

clearly conscious of looking up, though he continued to look straight in front. After the light had appeared to go some distance to the right, he voluntarily shifted his line of regard back to what he thought had been the position from which the light had started. The light then seemed to be blurred, because it was seen in indirect vision. Consequently, he argued that the fixation was relatively exact throughout.

Bourdon also mentions a tactual illusion which sometimes accompanies the autokinetic sensations and is comparable to the one mentioned above. When the point was turning to the left, the subject felt that everything was turning to the left; the table on which his arms rested, the room, his own body. In his left arm, there was the feeling of turning to the left. When the point of light seemed to be going down, it appeared to the subject that the table on which his arms were resting was under pressure.

[1] Charpentier (4) denies movements in the third dimension.

a slight drift to leeward. Generally, however, in getting to a goal which was diagonally away from the starting point, the light tacked to do it, going in the direction of the long and then of the short axis. Several times, when this light was hung diagonally, the bottom part apparently swung about through an arc as though "endeavoring" to get vertically under the top of the light.

G. Additional description.—In general, it may be said that the apparent movement of the light is, or may be, of three distinct types, depending upon the length of the fixation and upon the position of the light in the field of vision.

In the central portion of the field, particularly when the light is first fixated, there ensues a slight quivering of the light. Sometimes this is confined to the edges, but more often the light as a whole seems to sway slightly. Following this, the light appears to move in some definite direction, sometimes in a straight line and sometimes along an arc. The direction of this apparent movement, in the central portion of the field of vision, is decidedly irregular. It may be in any one of the 360 degrees or all in succession. The rate is comparatively slow. In the peripheral portions of the field, the movement of the light, where the first phase is present at all, is very similar to the above description, except that there is more uniformity in the direction of the apparent movement. Sometimes, however, the first phase seems to be entirely lacking.

Phase one shades with more or less gradualness into phase two. This consists of a more rapid movement, generally straight peripheralwards, and the velocity apparently increases the farther the light seems to move. The velocity of the apparent movement also increases directly the further peripheralwards the fixated light is placed. After a variable interval the velocity of the apparent movement grows gradually less. The light finally turns and enters upon phase three.

The third phase consists merely of a return sweep, generally of about the same velocity as that of the outward sweep or slightly less. The light, in this case, often seems to approach and even go past the point from which it started. From here, it repeats substantially the first two phases of the apparent movement, though the actual direction may be quite different.

Between phases one and two, the light may appear to stop, or it may describe an arc very slowly. On the other hand, the two phases may shade into each other without any apparent line of demarcation. At times, also, phase one may continue for a time, then phase two may start, continue for a few seconds, then phase one may start again, followed once more by phase two. Phase three seldom occurred with the length of fixation used in these experiments.

See P. 22 ff. Explanation of phenomenon

II.

Comparison of square light (1 cm. x 1 cm.) with the perpendicular light (5.6 cm. x 0.18 cm.) of the same area.

These tests were made only in the central portion of the field of vision, where the peripheral tendency would not overwhelm any possible effects of the shape of the light. In all 1300 tests were made with four subjects.

A. Rate of start.—The rate of start of the perpendicular light is, on the average, considerably greater than that of the square light of equal area, the latter requiring an interval of 6.1 seconds and the former 9.92 seconds (average for all subjects) in which to start the apparent movement. The slow rate of start of the perpendicular light as compared with the square one is interesting when it is correlated with the fact brought out by Dodge that a narrow, upright line is the best fixation object, the fixation movements being restricted to a very small area.

B. Direction of movement.—The effect of the shape of the light upon the direction of the apparent movement was entirely unexpected. The perpendicular light moved much more frequently than did the square one to the right and left, less frequently up and down and along the diagonals. The following table embodying the results of 800 observations will make this point clear.

	U & D		R & L		DIAG.	
	A	F	A	F	A	F
Sq. lt.	38.41	31.58	17.33	42.34	43.49	27.49
Pr. lt.	38.91	19.41	22.84	55.12	38.08	23.60

This was an entirely unexpected result, for it was thought that the suggestion due to the shape of the light would call forth up and down movements much more readily than the square light.[1] In the outer portions of the field of vision, the peripheral tendency due to eye position obscured the effects of the shape of the light, the pathway being similar to that of the square light.

C. Rate of movement.—In going to the right and left, the perpendicular light goes more slowly than does the square light, but in going up and down it goes more rapidly than does the square light.

D. Effect of fixating different parts of the perpendicular light.—No matter where the perpendicular light was fixated, it tended to move to the right and left more than it did up and down. When the top of the light was fixated, the right-left movements remained nearly constant, but the downward movements were lessened or inhibited entirely and the upward movements became correspondingly more frequent. Likewise, when the bottom part of the light was fixated, the upward movements suffered a similar checking or inhibition and the downward movements became much more frequent.[2]

E. Effect of using 2 square lights, 1 cm. square, one above the other.—In the first series of experiments, the contiguous edges of the lights were 1 cm. apart; in the second series, 3 cm. apart. Two subjects were used and a total of 194 tests was made at the zero point. When the upper light was fixated, the figure showed a tendency to go up more than in any other direction. When the lower one was fixated, there was a similar downward tendency. The two lights ordinarily moved in the same direction at the same time, but there were sometimes slight oscillations in one with no corresponding jumps of the other. In one case, while the upper light was stationary, the lower one rotated slightly about it.

There was no apparent difference in the rate of start corre-

[1] Bourdon (9) used an upright line 22 cm. by 1 mm., with which he found it difficult to procure a simultaneous movement of the whole line, but after a long fixation it did move to the right.

[2] Bourdon (9) found that when he fixated the upper portion of the light referred to above there was an apparent upward movement of the light.

lated with the distance apart of the two series, although in both cases it was slower than that of the single square light 1 cm. on a side.[1]

III.

Horizontal and oblique light of the same size and shape as the perpendicular.

Although not a great deal of work was carried out with these lights, (about 379 tests), enough was done to find out that they followed the same law of peripheral movement as the other lights. Like the perpendicular light, each moved in the direction of its short axis much more than did the square light and less in the direction of its short axis than did the square light. With each, there was a tendency, not so marked as in the case of the perpendicular light, for the light to move in the direction of the end fixated.[2]

IV. MAC ALLISTER'S FIGURES

A set of figures was prepared like those used by MacAllister in his study of "Fixation Movements". (17) These figures were, in general, of the arrow-head shape. The same light, turned four times through 90 degrees, ought to give quite different results if there is any influence in the shape of the light. The results do not bear out this assumption. The irregularity arose from the fact that the subject neglected one arm of the figure, paid attention to the other for a time, fixating one end and getting characteristic results for that kind of fixation, then shifted the attention to the other arm of the figure, causing often an almost right-angled turn in the pathway of the light.

[1] When Aubert (6) used two lights, he found that they moved simultaneously and in the same direction. Exner (8) discovered that a second light checked the liveliness of the illusion and retarded the rate of start. The closer together the two lights were, the more the movement was inhibited. Bourdon (9) also found that the two lights moved simultaneously in the same direction, but noticed that they underwent slight, momentary, relative fluctuations.

[2] Bourdon (9) when fixing the right end of the long, narrow light referred to above, found that it moved to the right.

V. EFFECT OF SIZE OF LIGHT ON ILLUSION

A. Rate of start.—With lights of the same brightness per unit of area and of the same shape, the size seems to have a direct influence on the rate of start. Averaging the 1520 tests of 4 subjects used in this experiment, the following results were obtained:

Size of light	Rate of start
1 cm. sq.	6.1 sec.
2 cm. sq.	8.8 sec.
3 cm. sq.	7.6 sec.
4 cm. sq.	28.9 sec.
5 cm. sq.	29.1 sec.

The bigger the light, the longer was the time necessary for the illusion to start in four out of five series of tests. Apparently, also, the brightness of the light has some effect, greater brightness acting like greater size, but no thorough-going experiments were carried out to test this point. Logically, if a light large enough and bright enough were used, the illusion ought to cease. It does, if the light is bright enough to illuminate intensely or even moderately the surrounding objects. With the largest light obtainable under the conditions of this experiment, a light about 10 degrees across and of brightness just insufficient to illuminate the surrounding objects, the illusion still persisted after a very prolonged fixation.[1]

B. Effect of size on the characteristics of the illusory movement.—In general, the larger the light is, the more it pauses and hesitates in the movement and the more difficult it is to get the movement started. With the largest lights, the movements were very ponderous and slow, with frequent long pauses. The smaller lights, 1, 2 and 3 cm. sq. moved almost continuously during the fixation. The light 4 cm. x 4 cm. was stationary 32% of the time that it was being fixated and the 5 cm. x 5 cm. light was motionless 25% of the time.[2]

[1] Bourdon (9) found that a low brightness value of the fixated light favored the quick production of the illusion. With the point hardly visible, it was produced very quickly; but with a brighter point, a longer time was necessary. Exner (8) mentions the same point.

[2] Bourdon (9) used a light 25 cm. in diameter placed at a distance of 1 m. from the eye. With this light, the apparent movements of the light were very difficult to obtain, were of small amplitude, appearing and disappearing quickly.

VI. THE ILLUSION IN MONOCULAR AND BINOCULAR VISION

In this series of experiments a round light 1 cm. in diameter was used. The three subjects who were used, completed a series of about 700 tests.

A. Rate of start.—Comparing the three kinds of lights, round, square and perpendicular, in binocular vision, the average rate of start of the round light is shortest, the respective rates being, in seconds, 5.12, 6.1, 9.92. The rate of start of the round light fixated binocularly is slightly shorter than with monocular fixation of either eye, but the difference is too slight to be of any considerable importance.

B. Direction of movement.—With both binocular and monocular vision, the light followed the law already mentioned of increasing the peripheral movement the farther the eye was swung in the socket. An interesting feature came out in connection with the monocular vision. With both the right and the left eye, the above law is followed on the average, but there are certain peculiarities which are deserving of mention.

With the right eye alone, the light showed a strong tendency to go either up or to the left, while there was little movement to the right or downwards.

With the left eye alone, this condition was exactly reversed. There was a decided increase in the movements downwards and to the right, while the movements to the left and upwards were considerably curtailed.

The binocular movement was not the resultant or average of the two monocular movements, but first one eye seemed to control the movement and then the other. The subjects were right-eyed for distant objects and left-eyed for near objects. This fact was brought out by having the subject observe the relative movements of near and distant objects produced by winking one eye and then the other, each eye fixating successively the near and far point. The 200 cm. between the light and the eye of the observer was normally just a little too far for the left eye. But the right eye, which ordinarily controlled the movement at the start, soon became fatigued and the left eye apparently stepped

in to relieve it. This in turn became fatigued and the right eye, which had had time to become relatively rested, came to the rescue, and so on as long as the fixation continued.[1]

VII. VOLUNTARY CONTROL

Voluntary control was possible for H. A. C. and H. F. A. It often took some time, but these two subjects were eventually able to make the light do what they wanted it to do. Various twists, winks, blinks, etc. were also effective to a certain extent. No new facts were brought out, but Carr's results were verified for these two subjects. M. R. F. was unable to secure voluntary control in the right-left direction, but could do so slightly in the up-down direction.[2]

[1] Gould says (11) that "with the right eye, the head being erect or level, the light will sometimes slowly move, with varying rapidity, and without regular rhythm or beat, to the right and often upwards........With the left eye alone the movements are usually, but not always, to the left and sometimes upward. I suspect the character of the movements will depend upon whether one is right-eyed or left-eyed." Carr (14) found that the average direction of movement for monocular and binocular conditions of observation varied slightly. Right or left monocular vision tended, with subject C., to deflect the direction to the right and left respectively. The binocular vision seemed to be either a mean between the other two or else to be coincident with one of them.

[2] Aubert (6) was unable to control the illusion voluntary. Bourdon (9) states that a sudden and unexpected sound caused the light to move in the direction from which the sound came. The idea of a certain direction, or thinking of making a movement in a given direction, tended to make the light go in that direction. This result was not always accomplished immediately, a considerable time interval often elapsing, according to both Bourdon (9) and Charpentier (4). Bourdon (9) found also that desired direction might be produced by finger pressure upon the eye ball which was not used in fixating the light. If the pressure was on the upper part of the eye ball, it caused an upward movement; if on the lower part, a downward movement; if on the temporal portion, an outward movement; and if on the nasal portion, no movement at all. Carr (14) found that voluntary control could be exerted upon the direction, velocity and extent of the movements and it was more effective for central eye positions. Volition was found to be rarely, if ever, immediately effective. Strain sensations of certain ocular and facial muscles were found to be necessary for volitional control. Passive attention to a sound had no influence upon the illusion, but active attention had a slight, transitory effect, causing a deflection of the illusion in the direction of the sound. Visual attention had a similar effect. Contraction of the hand and arm caused a slight disturbance, the extent and

VIII. SUGGESTION

There can be no doubt that suggestion plays a considerable part in determining the direction of the apparent movement of the light for certain positions. If the subjects obtained in any way a notion of how the light ought to go or was expected to go, it often went in that direction. The influence of the idea of the walls bounding the room, as was shown above, not infrequently affected the pathway of the light.

To test this problem more thoroughly, three näive subjects were obtained. These subjects, who were much interested in abnormal psychology, were told that the illusion was a new form of planchette which would form any simple figure or letter which they thought of while fixating the light. With one of the subjects, the suggestion worked perfectly, only one failure being made in 62 trials. The letters and figures were not always in their proper positions, sometimes being inverted, or suffering other displacements, but in all but one case, the desired letter or figure was formed. The subject was much surprised at this failure.

The other two subjects had difficulty in getting the illusion at first, but when they succeeded in obtaining it, the desired letter was formed in 80% of the cases.

IX. EFFECT OF LIGHT BACKGROUND

The illusion took place, though not so rapidly, if there was a light background which was not so bright as the fixated light. Indeed, the objects in the room could be dimly discerned, as could also the nose, the rims of the glasses of the observer, etc. Under these conditions, the illusion still took place, but not so readily. After some experience with the illusion, even the stars on a fairly bright night can be seen to make apparent movements. But this condition obtains only when the attention is so firmly

direction of which was irregular. Deep and slow breathing gave only ambiguous results. A strong contraction of the jaws produced a noticeable downward deflection of the movement under all conditions. A unilateral strain of the eye in any direction resulted in a pronounced deflection in that direction. Twisting the body, in many cases, produced a deflection opposite to that of the body torsions.

riveted on the light that the other visible objects fade from consciousness. The more variegated and complex the visual field, the more difficult it is to elicit the illusion.. Should a sufficient number of objects be in consciousness simultaneously, the illusion ceases.

X. EXPLANATION

The attempted explanations of the illusion have been of three main types. It has been asserted that the illusion is central in character. This means that the exponent of the theory (Gould-11) has been unable to find any peripheral factors, such as tears, muscae volitantes, which, in his opinion, could explain the illusion. Nothing, then, is left but some kind of indefinite cerebral action, such as 'unconscious purposes to move' (Aubert-6). It is much like the ancient theory of the support of the world in space, pushing back the unexplained to something which equally requires explanation. Undoubtedly, central factors are present during the illusion, for if there were not, we could not be conscious of the illusion. But this central condition must be aroused by some significant and adequate means, i.e., in the periphery. It is only in this way that the central processes can make a false interpretation of sensory data, thus satisfying the definition of illusion.

The other explanatory theories at least take account of some peripheral factor. Exner (8) attributes it to the "circles of action of the retina". In explaining his "circles of action", Exner refers to the fact that a page of print, for example, will look merely like a gray rectangle at a certain stage of illumination. From this he argues that not only the part of the retina directly stimulated is excited, but the excitation overflows into the neighboring portions. The distance to which the stimulation from any one object radiates is called the "circle of action". If this overflow of stimulation is present in the case already mentioned, he argues, it is also present when a black spot on a white background is fixated. The awareness of this wandering about of the excitation within the "circle of action" produces the slight illusory movement of the spot.

This principle alone is insufficient, however, to explain the more extended illusory movements of a faint light in a dark room described by Charpentier and Aubert as sometimes amounting to 30 degrees. To account for these, Exner, after repudiating eye movements, which according to him diminish or prevent the illusion entirely, calls to witness the incompleteness of our orientation in the visual field and also the inexactness of our visual judgments of direction without control through retinal images. The more extended of the seeming movements are, then, illusions originating in the radiating tendencies of the stimuli. The unreal nature of the movements thus suggested we have no adequate means of detecting.

It is doubtful if the stimulation wanders about in the retina as Exner asserts that it does especially at the fovea; or, if it does wander, that the accumulation of the energy is first in one direction and then in an other as his theory seems to necessitate.

3. The remaining type of theory which might be called the eye movement theory, may be any one of three kinds. The first kind asserts that the illusion is due either to the unconscious fusion of the unconscious eye movements which are always present during fixation, or to the shifting retinal impression of the light brought about by the unconscious eye movements. To my mind this theory has been adequately refuted by Carr.[1]

[1] While admitting that these unconscious fixation movements of the eye may play some unimportant part in the illusion, Carr (14) stated that "theoretical considerations may be urged against the theory as the *sole* explanatory principle. Why should the eye movements become integrated? What is the mechanism of this unconscious integration? Why does not the integration occur under normal conditions of perception? How and why should the process of integration be modified by the factor of position, etc.? Why should the process of integration achieve such diverse results under similar conditions? Factual objections may be given . . . . . Some people can obtain the phenomenon for some eye positions, but not for others. The illusion does not occur in normal perception. No one can deny the presence of involuntary eye movements under these conditions. If the eye movements produce the illusion in one case and not in the other, at least some secondary principal of explanation is necessary."

If a small, bright light is placed in the center of a dim larger one, Exner (8) maintains that while both move, the small spot wanders to and fro in the larger area. The movements of the latter are of the same character that they would have been if the central bright spot had been absent. The least eye movement checked the movement of both points. Exner conse-

The second eye movement theory asserts that the illusory movement of the light is due to driftings of the eye of some considerable extent—a sort of nystagmic condition. This approaches very closely to Carr's second type of illusion (14), and can not serve as an explanation of the first type for several reasons. In the first place, in obtaining the form of the illusion, where the fixation does not leave the light, there is not sufficient wandering of the eyes, as was found by Carr, by actual observations of the eye experiencing the illusion. Experiments with after-images have shown that there is no appreciable drifting of the eyes from the fixated light.[1]

The third eye movement theory has been variously stated, but the key note of it seems to be that some sort of tension of the muscles is produced, either by fatigue of some muscle or group of muscles, or by some strain which has become increasingly greater in order to keep the eye in its position in the socket. This gives rise to a condition of excitement or lack of balance in the neuro-muscular system of the eyes. The illusion is somehow

quently argues that eye movements cannot be the cause of the illusion. Carr's (14) experiments on the behavior of the light and a previously induced negative after-image, cited below, point to the same conclusion. Bourdon (9) and Simon (12), who repeated Exner's tests as to the relative movement of two objects, found that when the two objects moved, their positions relative to each other remained constant.

The main supporters of the first type of eye movement theory are Hoppe (3), Bourdon (9), and Simon (12). Dodge (13) gives an explanation which depends upon the same underlying principle, but differs in form of statement. This theory will be considered below.

[1] The following is a paraphrase of certain passages in Carr's article (14). To test the effect of involuntary eye movements, the relative movements of the light and a previously induced negative after-image were observed. In illusions of the first type, the negative after-image remained with the light and participated in the illusion. However, there were slight, irregular oscillations due to the involuntary shifts of the eye ball. Oscillations occurred in every test, though there were periods in which none could be detected. Generally no effective eye movements occurred during the marked and significant directional changes of the illusion. When such eye movements were present, their direction bore no constant relation to the illusory phenomenon. The results suggested that possibly steadiness of fixation might favor the velocity and uniformity of the movements. The relative oscillations of the light, and the after-image were due to irregular movements of the light.

caused by the conscious or unconscious interpretation of these conditions and factors.[1]

The objection to this theory is the alleged fact emphasized by Dodge (13) that the kinaesthetic sensations from the eye muscles can give us no information at all of eye movements. Conversely, strain on the eye muscles ought not to give us any reliable information concerning the position of anything in the visual field in relation to the head, even when it is directly fixated.

If Dodge's contention be correct, the only factor left to give any information concerning the movement of visual objects is some retinal condition, such as the succession and fading away of positive after-images. And Dodge would explain the illusion (13) as due to these after-images which are made possible by the shifting visual impressions brought about by the unconscious eye movements. But this is again referring it back to the unconscious eye movements and we have seen above that there are very cogent reasons for abandoning this type of explanation. It may be added that such after-images were never reported by the subjects.

Let us now turn to a theoretical consideration concerning the conditions under which an object may be seen to move. The instantaneous perception of movement must depend upon peripheral factors in the eye. These are limited to three classes of phenomena: the shifting of the retinal impression, the kinaesthetic cues from the various eye muscles, and the cutaneous sensations brought about by the pressure of the cornea and the lid and the temperature sensations (if such there be) aroused by exposing more or less of the cornea.

If all of these factors are examined, some light may be thrown upon the problem. The first explanatory assumption mentioned above emphasized the shifting of the retinal impressions, which would leave positive after-images, thus giving information as to the direction and amount of movement. In addition to the objections to this type of explanation of the illusion already cited, may be added the following: The unconscious eye movements come very frequently, averaging about 9 to the second and are

[1] The writers who advocate some form of this type of explanation are Charpentier (4) and Carr (14).

of small amplitude, seldom, if ever, amounting to more than 2½ degrees. On this assumption, the illusory movement ought to begin as soon as the unconscious eye movements take place, an average time of 1/9 of a second. But this is not the case. There is, indeed, a slight quivering of the light immediately upon fixation which persists until the illusion has started. This might be explained very plausibly by the unconscious eye movements, but these slight shifting movements do not constitute the illusion.

In the second place, if this theory were correct, the illusory movements ought to be quite variable, extending for a couple of degrees in one direction, then changing, but constantly circling about the point originally fixated. How could the slight eye movements account for illusory movements of the light amounting to 40 or 50 degrees in one direction?

Are the cutaneous sensations produced by the varying relations of cornea and lid sufficient to account for the illusion? Probably not, for if they were of any value, it ought to be in giving information as to whether the eye were stationary or moving. But how could this information help in experiencing the illusion? It is the very thing that the subject must be prevented from knowing in order to ensure the appearance of the illusion, for if he knows that the eye has moved, he may well judge that the light has not. In addition, if the cutaneous sensations of the lid are analogous to those of the rest of the body, they are soon fatigued and so could give the information to the subject for only a short time at best. The explanation of the illusion does not lie in this direction.

The only thing left is some sort of kinaesthetic data from the muscles. We have seen above that such data cannot be afforded by actual eye movements whether conscious or unconscious. The only condition left, then, is to be found in the strain sensations or nerve impulses coming from the eye muscles while the eyes are relatively motionless. A number of things which contribute to point to this conclusion will be taken up in due order.

But this is not the only factor which has to be taken into account in giving the explanation. The other one is this, that there is but one thing visible in the field of vision, or, if there are several, they interfere with the illusion.

The typical conditions of the illusion, then, are as follows: There is nothing visible in the field of vision except the fixated light. The only factors capable of informing the subject whether the light has moved or not are some shifts in our ideational space relations, brought about by muscle strain and tactual elements coming from the head-rest and table. The head-rest and table occasionally participate in the illusion, being more likely to do so, the stronger the autokinetic illusion is, and so may be neglected as a contributing cause of the illusion.

The illusion might conceivably be occasioned either by a shift in our ideational space construction while the light remains stationary, or by an apparent movement of the light in the stationary space. Either condition would satisfactorily explain the illusion.

When the eye is at any given position in the visual field, it is held there by the balanced action of the six extrinsic eye muscles. These muscles are not all of equal strength and some will become fatigued more quickly than the rest. When they are in this condition, it will take more of an effort, usually reflex in character, to hold the fixation constant; the fatigued muscle will be more strongly innervated. Consequently, more impulses, kinaesthetic and others, will be sent to the higher centers from that muscle. As these impulses have previously been associated with eye movements in a given direction, and since the fixation remains with the light, the subject will think that the light has moved in the direction in which the strain has been exerted. It produces the illusion of a pursuit movement. It is a matter of indifference whether the nerve impulses from the muscles arouse consciousness immediately or not, so long as they are capable of overflowing into other centers and thus produce the consciousness of movement.

The movement must also be attributed to the light and not to the ideational space, for if it were attributed to the ideational space, the movement would be in the direction opposite to that of the strain, whereas it actually is in the direction of the strain.

An illusion very similar to the autokinetic sensations is also experienced if the arm is extended in any direction and held in a stationary position by pressing a small piece of wood against the end of the finger strongly enough to prevent movement but

not strongly enough to support the arm. Under these conditions, the arm seems to be moving upward, or in the direction in which strain must normally be put to keep the arm stationary.

If the arm is fatigued by holding it for a considerable interval in one position, e.g., straight out from the shoulder at the side, the illusion is much more striking. In the tests performed, the illusion was always in the direction of the muscular strain.

The illusory movement starts when the original muscular balance is sufficiently upset so that the extra innervation necessary to keep the fixation constant becomes strong enough to arouse the kinaesthetic and organic impulses and, through them, the associations mentioned above. The longer the increasing strain on that muscle or set of muscles continues, the longer will the movement continue in that direction. The shifts of direction of the illusion are due to the changes in muscular balance, on account of other muscles being subject to relatively greater strain, and consequently calling for greater innervation, with its accompanying results. Towards the center of the field of vision, there is naturally not so much strain on any one muscle as there is towards the periphery, and the balance is upset more frequently. Consequently, the direction of the illusory movement is more likely to be shifting and erratic towards the center of the field of vision. But as the eye is turned farther and farther, the strain on one muscle or set of muscles becomes greater and more constant and the resultant movement is therefore more regular and also faster.

Since voluntary control of the illusion is possible only by means of some such strains, it becomes easily explicable on this hypothesis. Attention in a given direction without looking in that direction means greater innervation (with its usual results in the muscles) in that direction without any resulting movements. Consequently the illusion takes place in that direction. In fact, Carr's statement (14) that steadiness of fixation seems to be a favorable condition for the illusion fits in remarkably well with the strain theory, for if the eyes were not steady there would be less preponderance of strain in any one direction.

The fact that with certain persons the illusion has a great tendency to go in a particular direction, as the right-left tendency

of M. R. F. and the upward tendency of H. F. A., is also easily explained. The strength of the muscles was ascertained by using prisms. In the first case, the external and internal recti are weak, tiring easily and thus causing a right-left tendency of movement. In the second case, the external and internal recti are abnormally strong, were difficult to tire, so the movements in the right-left direction were few.

The perpendicular light showed a strong tendency to move to the right and left because there was not the same restriction to actual up and down movements that there was to those in the right-left direction. Consequently, the same amount of strain had not so much chance to arise. If, then, there is more strain in the right-left direction without corresponding eye movement, the light, according to the above assumption, ought to move oftener in the right-left direction, which it did. The reason for the slow movement of this light in the horizontal direction was because there was no very great superabundance of strain in one direction. It was enough, however, to produce the movement.

When the top of the perpendicular light was fixated, the only chance for free eye movement was downwards while the fixation was still on the figure. There is no reason why the right-left tendency of the light should change under these conditions, but there should be more strain on the muscles raising the eye without actually moving them. Consequently, the direction of the illusion ought to be upwards, which was the case. For exactly the same sort of reason, the light had a decided downward tendency when the bottom part of it was fixated.

Small areas move more readily and easily than the large ones because there is less chance for wandering of the eyes. The less wandering there is, the sooner the strain impulses should arise, and the sooner these arise, the quicker the illusion should start. Also, the more intense the strain sensations become, the longer and faster should the light move. This is exactly the condition met with when small lights are used.

Suggestion was effective because of a tendency to move the eyes in the suggested direction without actually doing so. Therefore strain would be put upon the muscles moving the eye in that

direction, which would result in the illusion of movement in that direction.

Pathological cases and positive experiment tend to be strongly in favor of the strain theory of the illusion. As an illustration of countless numbers of cases of this character, may be cited the one taken by James (16) from Helmholtz. "When the external rectus muscle of the right eye, or its nerve, is paralysed, the eye can be no longer rotated to the right side. So long as the patient turns it only to the nasal side it makes regular movements, and he perceives correctly the position of objects in the visual field. So soon, however, as he tries to rotate it outwardly, i.e., towards the right, it ceases to obey his will, stands motionless in the middle of its course, and the objects appear flying to the right, although position of eye and retinal image are unaltered."

The conditions in the two cases are quite similar. In each, the fixation or position of the eye remains constant, the eye is not moved, but in each case, data which have meant movement in the past are present and are interpreted to mean movement. In both cases, the illusion of movement is a secondary affair, caused by another illusion, viz., that of pursuit movements. If during a pursuit movement, the object remains steadily fixated or in the same peripheral position, then the object must be moving, is the interpretation made, the rate being determined by the rate of the illusory pursuit movement.

The results of an experiment performed at the Psychological Laboratory at the University of Michigan[1] tend to bring out the same point under the normal conditions of the illusion. The subject was allowed to fixate the light until the illusion was well started, then the light was turned off and left off for a few seconds. The subject was directed to keep his eyes where the light had disappeared. The illumination in the room was then turned on and he was asked to tell where he was looking.

In no single case was he looking at the place where the light was, but in about 90% of the cases was looking at a point approximately opposite to that in which the illusion was going

[1] The author takes advantage of this opportunity to thank Professor John F. Shepard of the University of Michigan for the suggestion which led to the carrying out of this experiment.

when the light was turned off. In the other cases, the fixation point was on the same side of the light as the pathway of the illusion, but between the place where the illusion had appeared to stop and what had been judged to be the starting place of the illusion.[1]

This experiment proves that there is an unusual strain on a certain set of muscles while the illusion is being experienced. When there is no fixation point, the eye muscles tend to resume their balance, or to keep constant the amount of strain that was present with the disappearance of the illusion, thus pulling the eye in the direction opposite to that which the illusion had apparently taken. It was found that when the strain on the muscles was increased in the way that would be done under normal observation of the illusion, the eyes were very much nearer the place at which the light had disappeared when the illumination was turned on.

Another kind of experiment points to the same conclusion. If a great strain is put upon the eye to make it move in some definite direction while the eye-ball is held stationary, the illusion takes place in the direction of the strain.

Taking everything into account:—the results of the special experiments just mentioned, the neatness with which the strain theory explains the facts of the illusion, the entire inadequacy of any other explanation—it seems that some such hypothesis as that outlined above affords the only satisfactory way of explaining the illusion. It successfully avoids the difficulties raised by Dodge, and is supported by practical and theoretical data.

[1] These variations in direction between the pathway of the illusion and the point fixated when the light was turned on were probably due to shifts in muscular tension. They probably would have produced changes in the direction of the illusion had the subject still been fixating the light.

THE AUTOKINETIC SENSATIONS

Historical Review

Despite the frequent references to the literature given in the previous pages, the lack of any connected historical sketch in English seems to justify a brief attempt at such a statement.

The term Autokinetic Sensations is used to describe the illusory movement of a small object or a collection of small objects, which is seen after a longer or shorter fixation, against a relatively uniform background. Such apparent movement of the object is possible either in the light or in the dark. Historically, three main forms of the illusion have developed. In the day light, for example, a small black spot on a white background may be seen to move. This type of the illusion has been called by the Germans "Punktschwanken". In the dark, there are two forms of the illusion: first, the movements of the stars, called the "Sternschwanken", which was the form of the illusion first noticed; and, secondly, the movement of a faint light in the dark room, which has often been designated by the term "Scheinbewegung". Strictly, the term Autokinetic Sensations which was coined by Aubert was applied only to the last mentioned, but since all three are so similar and obviously depend upon the same causes, it seems justifiable to broaden the term to include all three types.

Chronologically, the first authentic information concerning the illusion comes from Humboldt (1). While upon a mountain peak 10700 feet above the level of the sea during the course of some investigations in Teneriffe, Humboldt saw the stars moving about in a most bewildering way. This phenomenon was visible either with a telescope or with the naked eye. After lasting for some 7 or 8 minutes, it ceased and soon the sun appeared above the horizon. Concluding that the stars actually moved Humboldt

gave the name "Sternschwanken" to his discovery. Under this name it was frequently mentioned in the astronomical literature of the next half century.

The discovery that this phenomenon was an illusion was left to Schweizer (2). This fact appeared when Schweizer had the same star observed simultaneously by several different observers. It often happened that the different observers saw the same star going in different directions at the same time. If this was so, it could not be the result of any actual movement of the stars, so the obvious conclusion was accepted, namely, that the phenomenon was an illusion.

Turning now to the reports concerning the peculiar characteristics of the various types of the illusion, we shall begin with the "Punktschwanken".

Schweizer, Hoppe and Bourdon found that a black speck on a white background, as for example, a speck on a wall, would appear to move after a few seconds fixation. These movements were often irregular in direction and were much smaller than the apparent movement of the stars. Schweizer states that the spot, after its apparent movements, always returns to its original position. Hoppe and Bourdon do not mention this fact. The appearance reminded all of the observers of the movements of an insect, which was either crawling slowly, or which, stuck to the wall, was trying vainly to escape, now in this direction and now in that. Sanford states that the spot ordinarily moved either to the right or to the left for him.

Aubert calls attention to the fact that objects without sharply marked contours, such as distant flag staffs, masts, etc. appear to move after a period of steady fixation.

Turning now to consider the illusory movements of the stars, we find that this phenomenon has been mentioned by Humboldt, Schweizer, de Parville, Charpentier and Gould. According to Humboldt, the direction of the apparent movement was as follows:—The stars first went upward, then turned sideways and finally fell to their original position. Schweizer states that they either moved in ellipses or circles, going sometimes clockwise and at other times counter clockwise, or else they moved pro-

gressively. In either case they returned to their original position. De Parville says that the stars appeared to oscillate as if joggled and Charpentier holds that the movements were small, changed direction rapidly and that slight concomitant eye movements could be noted. Gould considered a star an unsatisfactory object from which to obtain the illusion, both on account of its dimness and because there are generally several of them close together. Yet with practice, he succeeded in obtaining the illusion with stars.

The extent of the illusory movements with the stars is relatively limited. Schweizer says that it may amount to several degrees and Charpentier states that it was small.

For Humboldt the illusion lasted for 7 or 8 minutes, then stopped.

Humboldt holds that the movement as visible through a telescope, though de Parville denies this. For de Parville the illusion stopped with very rapid blinking.

The apparent movements of an artificial star in the dark room have been studied much more thoroughly than either of the above illusions, and, consequently, may be treated much more in detail.

Carr found that this illusion might occur under three typical conditions:—

1. The point of fixation remained with the light and participated in the illusory movement. (2) The point of fixation apparently remained stationary and the light moved away from it. (3) A combination of the above two types occurred. The second type of illusion was less in extent, was less rapid, its direction was more uniform during any one test and was more constant from test to test for the same eye position than was the illusion of the first type under corresponding conditions. The illusion of the second type finally stopped. Accompanying this type of illusion were eye movements of about the same amplitude as the illusion but opposite in direction. A previously induced negative after-image remained motionless while the light appeared to move. On the other hand, in the first type, the after-image remained with the light and participated in the illusion.

(A). *Universality of the Illusion.*

The greater part of the experimental work, however, has been done in connection with the illusion of the first type, so it will be profitable to take it up in considerable detail.

Charpentier found that nearly all of his subjects experienced the illusion, but does not give the percentage of those failing to do so. Exner found that there were two men in his laboratory who could not, at a single observation at least, detect any evidence of movement. Gould states that about one half of his observers did not get any decided movement of the light, but only a slight quivering or vibratory movement. Carr had one subject who could experience the illusion under no condition. Another subject obtained the illusion in the lower half of the visual field in only 50% of the cases. This subject was unable to obtain illusions of the second type.

(B.) *Characteristics of the Illusion.*

(1) Rate of start. Nothing very definite has been worked out concerning the rate of start. Most of the investigators who mention this fact, say that it starts 'in a few seconds', or that 'it soon appears to move'.

(2) Direction of movement. Charpentier, who observed the illusion monocularly by looking through a tube at a light in a dark box found that the direction of movement was variable, but most often it traced a slight curve, moving outwards and upwards, though sometimes the direction was quite different. It sometimes described curves and zig-zags. Sometimes the direction was different in different tests. Bourdon found that the direction of the apparent movement was irregular. Sometimes it continued for a long time in the same direction. Hillebrandt, Sanford and Carr found that the direction of movement for successive tests for the same position depended upon the position of the eye in the head when fixating the light directly. In the central part of the field of vision, the direction of the apparent movement was quite variable. Here it was more likely to be curved than straight, while towards the periphery, especially

after the eye had turned through 40 degrees the light was quite likely to go in the same direction as that of the eye strain in practically a straight line for successive tests, this direction being peripheralwards.

(3) Velocity of movement. Charpentier found that the movement was like that of a shooting star, but less rapid, having an apparent angular velocity of at least two or three degrees per second. For Bourdon the movement was sometimes slow and sometimes rapid. Carr found that the velocity of the apparent movement depended upon certain conditions. It was often slow and irregular, especially at the central part of the visual field, but under conditions of fatigue from constrained eye positions, the light with some individuals often moved with an apparent velocity of fifteen to twenty degrees per second, giving the impression of a sky-rocket or of a rapidly moving shooting star.

(4) Amplitude of the movement. Charpentier found that the extent of the movement varied, though it might reach and even exceed thirty degrees. Exner gives about the same figures, stating that the apparent displacement often amounted to twenty or thirty degrees. Bourdon states that the movements had a large amplitude, the displacement being sometimes more than thirty degrees. Carr found that the extent of the movements was greater for extreme peripheral positions. Inside of the thirty degree zone, it was aimless in character. Under conditions of marked ocular fatigue and constrained eye position, the illusion for one subject was at least sixty-five degrees in extent.

(5) Duration of the movement. Exner found that the movement continued as long as he fixated, while Bourdon discovered that the point sometimes reached a fixed limit, undergoing slight, abrupt displacements from time to time about this final position.

(6) Movements in the third dimension. Charpentier says that no third dimensional components were *ever* noticed. The light always remained at the same distance from the observer. The other writers do not touch upon this point.

(C.) *The illusion in indirect vision.*

Charpentier found that the illusion occurred in indirect vision. Bourdon states that it is not necessary to fixate the point, though

the amount of apparent movement was smaller when the point was not directly fixated.

(D.) *The illusion in monocular vision.*

Gould found that with the right eye alone, the head being erect or level, the light often moved to the right and often upwards. With the left eye alone the movement was usually but not always to the left and also sometimes upward. Carr found that right or left monocular vision with subject C tended to deflect the direction of the apparent movement to the right and left respectively. With binocular vision it seemed to be either a mean between the other two or else to be coincident with one of them.

(E.) *The effect of incidental factors upon the Illusion.*

(1) The size of the light. Bourdon found, by fixating a luminous disc, 25 cm. in diameter placed 1 meter from the eyes, that the apparent movements were very difficult to obtain and when once obtained were of small amplitude, appearing and disappearing quickly.

(2) The brightness of the light. Exner holds that the less bright the light is, so long as it is foveally visible, the more lively is the illusion. Bourdon says that feeble brightness of the point favored the production of the illusion. With the point scarcely visible, it was produced very quickly. Yet a weak intensity is not indispensible. Brilliant spots, after a time, apparently move.

(3) The shape of the light. Bourdon found, when fixating a line 22 cm. by 1 mm., placed vertically at a distance of 1.5 m. from the eyes, that it was very difficult to get a simultaneous movement of the whole line. He finally obtained, however, a very marked movement of the line as a whole to the right or in the direction of its short axis. When he fixated the upper end of the line there was an upward movement. When the same line was turned horizontally, he finally succeeded in obtaining a slight but marked downward movement of the whole line. While fixating the extreme right end of the line, the whole figure seemed to go to the right.

(4) Voluntary eye movement. According to Charpentier, the fixation might be voluntarily changed around the object without stopping the illusion or changing its direction. According to

Exner, the least eye movement checked the movement of the point. Gould maintains that steadiness and continuousness of the gaze make the illusion more manifest and pronounced. To observe the effect of voluntary eye movement, Carr directed his subjects to rotate the eyes from one edge of the light to the other from time to time during the illusion and to note any coincident disturbances in the apparent movement. Two lights were used at different times; a square one, 1 cm. on a side, and a light in the shape of a cross which allowed movements of 10 or 12 cm. in length. The effects were found to be similar for both lights. Frequently no disturbance was noted, though generally a slight momentary influence in the same direction as that of the eye movements was present. The disturbance was momentary and never more than 2 or 3 cm. in extent. No permanent influence upon the direction or velocity of the light was ever noticed. Observations were made while attempting to fixate a distinct point on the light. These were compared with those obtained when the fixation was allowed to wander over the light at will. No differences in direction or velocity could be noted between the two conditions of observation. The fixation was also shifted suddenly for various distances and directions away from the light during the illusion. Such movements of more than two degrees tended to destroy the illusion temporarily, and the light appeared to be located nearer its original position. When the eye was held stationary in the second position, the illusory motion again appeared.

(5) Involuntary eye movements. To test the effect of involuntary eye movements, Carr observed the relative movements of the light and a previously induced negative after-image. In illusions of the first type, the negative after-image remained with the light and participated in the illusion. However, there were slight, irregular oscillations due to the involuntary shifts of the eye-ball. Oscillations occurred in every test, though there were periods in which none could be detected. Generally, no effective eye movements occurred during the marked and significant directional changes of the illusion. When such eye movements were present, their direction bore no constant relation to the illusory phenomenon. The results suggested that possibly steadiness of

fixation might favor the velocity and uniformity of the movements.

(6) Actual movement of the light. Aubert stumbled across the illusion while working on the perception of motion. He found that sometimes movement was seen when there was no objective movement, while at other times quite rapid objective movements were undetected. The direction of the illusory movement was in all but three cases the same as that of the actual movement of the fixation object. Carr moved the light objectively in a horizontal direction either two or five cm. at varying rates of speed. For those positions where the illusion normally moved in a vertical direction, a spiral or cork screw effect was obtained. When both moved in the same direction, the illusory movement was alternately accelerated and retarded. So far as could be observed, objective oscillations did not disturb the illusion in any way, for the total result was a composite of the oscillations and of the normal illusory movements for that position.

(7) Winking. Aubert found that by means of an intentional wink, he could often check this apparent movement, keeping the object in its correct position, but this did not always occur. Gould maintains that the inhibition of winking makes the illusion more pronounced. Carr found that inhibition of winking exerted no influence upon any characteristic of the illusion. Voluntary winks were sometimes effective and sometimes not, their effect being more frequent for central eye positions. With voluntary winking, an increase of the effect was obtained as long as the innervation could be increased.

(8) Finger pressure upon the eye ball. Charpentier found that finger pressure upon the eye not used in perceiving the illusion exerted certain influences upon the direction of the illusory movement. If the pressure was on the upper part of the eye ball, it caused an upward movement; if on the lower part, a downward movement; if on the temporal side, an outward movement; and if on the nasal side, no movement at all. In the above cases, the resulting direction was independent of the position of the eyes in the head.

(9) Head-rest. According to Exner, it makes no difference whether a head-rest is employed or not. According to Gould,

immobility of the head is a favorable condition for a pronounced illusion.

(10) Direction of the line of regard. Charpentier holds that various turnings of the eyes did not retard, prevent or influence the illusion in any noticeable way. Hillebrandt found that when the light was placed in the extreme periphery of vision so as to be fixated with great difficulty, the illusion took place towards the periphery and was the more striking the longer the fixation was continued. Exner contends that the direction of the illusion depends upon the direction of the line of regard. Bourdon found that, if in fixating the point, the observer shifted the line of regard without turning the head in relation to the body,—above, below, to the right and to the left—the movement of the point tended likewise to be respectively up, down, to the right or to the left. Carr's experiments confirm the belief that the position of the eyes in the head is a determining factor in the illusion. He found that its most marked effect was upon the direction of the illusion. Averaging all the cases, it was found that with subject C there was a marked tendency for the light to move towards the periphery of the field in 88% of the cases. This peripheral tendency increased with the distance of the light from the center of the field. The average percentage for all positions within 30 degrees of the center was 75. Outside of the 30 degree zone, the average was 95%, and for extreme fixation positions the percentage was 100.

(11) Previous eye position. To test this point, Carr directed his subjects to turn the eye towards the light from various directions at the beginning of the illusion. Care was taken to choose such distances that no after-effect of the previous fixation was present. A slight temporary disturbance of the same direction as that of the eye movement was generally observed. But no permanent effect was exerted. When the previous fixation was of longer duration, any eye position was found to exert not only a characteristic effect upon the illusion while the eye was in that position, but also to leave an after-effect which modified the direction and velocity of the illusion in a characteristic way for subsequent eye positions. The duration of the after-effect varied from nothing at all to one minute. It was a function mainly of

the distance and direction of that position from the center of the field and the length of time the eye maintained that position.

As a result of this experiment, Carr divided the field of regard into two zones, an inner and an outer. In the inner zone, the movement tended to be towards the periphery and in the outer zone it tended to go towards the center. This latter direction of movement was always quite rapid and was followed by a return sweep. The inner zone was elliptical, the shorter axis being vertical. The length of the two axes was approximately 45° and 50°. The influence of the outer zone was more pronounced and characteristic than that of the inner. The direction was practically constant for successive trials at the same position. There was found to be a minimum duration of fixation necessary to secure any result, this period decreasing with the eccentricity of the fixation position. There was a certain period of fixation necessary to secure the maximum result for any position. After the maximum of effect had been obtained, further fixation decreased the effect. Subject A had three zones, the outer and inner corresponding to subject C's outer, and a middle, corresponding to C's inner.

(12) Fatigue. According to Charpentier, the illusion takes place readily after prolonged mental labor, such as a lecture, a long conversation, etc. Bourdon agrees with this, and would add general muscular fatigue. He considers also that retinal fatigue and fatigue of the eye muscles cause the illusion to take place more easily. Stimulation by alcohol and tobacco is in addition a favorable condition.

(13) Attention. Charpentier found that passive attention, such as that given to a sudden and unexpected sound, caused the light to move in the direction from which the sound came. Carr found that passive attention to a sound had no influence upon the illusion, but active attention had a slight, transitory effect causing a deflection of the illusion in the direction of the sound. Visual attention had a similar effect.

(F) Voluntary control. Charpentier states that the light may be made to move in a desired direction by thinking of a given direction, perceiving another object in that direction, or by thinking of performing a movement in that direction. This was

not always true, but it occurred in the majority of the cases, the percentage of successful cases and the length of time necessary to keep the attention focused upon that idea not being given. All of the observers at times succeeded in this voluntary control. Aubert, on the contrary, was unable to secure voluntary control of the direction of the apparent movements of the light. Bourdon, however, agrees with Charpentier in the ability to control the direction of the movement voluntarily, by thinking of a given direction or even by looking in that direction a little from time to time. At times it was necessary to attend for a considerable length of time before the new direction was obtained. At times, also, he obtained a resultant of the old direction and of the one of which he was thinking. The possibility of voluntary control was confirmed by Carr's tests. This control could be exerted upon the direction, velocity and extent of the movements and was more effective for the central eye positions. Volition was found to be rarely if ever immediately effective. Strain sensations of certain ocular and facial muscles were found to be necessary for volitional control.

(G) The effect of the tension of various muscles. Carr found that long continued and intense contraction of the hand and arm caused a slight disturbance in the majority of tests, the extent and direction of which was irregular. Deep and slow breathing gave only ambiguous results. A strong contraction of the jaws produced a noticeable downward deflection of the movement under all conditions. A unilateral strain of the eye in any direction resulted in a pronounced deflection in that direction. Twisting the body in many cases produced a deflection opposite to that of the body torsion. After fatigue had been induced, it was found that a rotation of the head around the anterior-posterior axis caused a change in the direction of the illusory movement.

II. Other Illusions Involved.

One of Bourdon's subjects experienced an interesting tactual illusion which accompanied the apparent movement of the light. While the point was going to the left, for example, this subject

felt that everything was turning with the point, the table on which his arms rested, the room and his own body. His left arm felt as though it were turning to the left. When the point of light seemed to be going down, it seemed to the subject that the table upon which his arms rested was under pressure, like a ship which is forcing its way down into the water. Another illusion noticed by Bourdon in studying the apparent movement of the light was the false consciousness of the direction of the line of regard. If the point had seemed to go up 20 degrees, the observer was clearly conscious of looking up, though his eyes were straight to the front. After the light had appeared to go some distance to the right, he voluntarily shifted his line of regard back to what he thought had been the position from which the light had started. The light then seemed to be blurred because it was seen in indirect vision and the eyes and head were turned to the left. Consequently, he argued that the fixation was relatively constant throughout.

III. The Presence or Absence of Eye Movements.

The principal experiments to test this point were performed by Carr, though certain others will be taken up under the consideration of the movement of two or more lights. Carr used two methods, the after-image method and that of observing the eye which was experiencing the illusion directly through a horizontal telescope. By the first method, as has been mentioned above, there was disproof of any eye movements sufficient in magnitude to account for the extended illusions of the first type which he obtained. The observation of the eye through the telescope gave identical results. There were always present the slight involuntary twitchings of the eyes, but no extended movements or even drifts in illusions of the first type, but in this second type there were large movements opposite to the direction of the illusion.

IV. The Illusion with Two or More Fixation Objects.

Charpentier maintains that with a group of small points close together, the illusion still persists. Aubert adds the information

that both objects move simultaneously and in the same direction. Exner says that the presence of a second light retards the illusion, this effect being greater the closer together the two lights are. Nor did he find that the two objects moved simultaneously in the same direction. To test this point he used a black spot 1 cm. in diameter with a needle hole in the middle. This was so adjusted that the black spot and the bright hole could be seen easily. The result of fixation was that both seemed to move, but often the spot of light wandered rapidly to and fro inside of the black circle, often changing direction, but never reaching the edge of the black speck. The latter made movements of the same character that it would have made if the central bright spot had been absent. So the two movements were often independent of each other and could not be due to eye movements. Simon repeated Exner's tests as to the relative movement of two objects. Exner's results were not confirmed. When the objects moved they always moved in unison. Bourdon, in testing the same point, used a pale luminous disc 25 cm. in diameter which had an opening 2 mm. in diameter in the center. The movements of the point were easily observed, though it was difficult to follow the motion of the disc. The disc nevertheless followed the point, for when at certain moments, Bourdon paid attention to the apparent position of the disc, he observed that it corresponded to that of the point. Bourdon also used two lights side by side. It made no difference whether they were 4 or 22 mm. apart, whether they were placed horizontally or vertically with relation to each other. The two lights appeared to move simultaneously and to oscillate together. The movement was however, of but small amplitude. With a more complex figure, he further verified the simultaneous movement of the different parts of the figure.

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